BOLOMETRIC $YBa_2Cu_3O_{7-x}$ INFRA-RED DETECTOR

Indexing terms: Superconductors, Thin film devices, Infra-red detectors, Yttrium compounds

Results of the measurement of optical detection in $YBa_2Cu_3O_{7-x}$ superconducting epitaxial films at a wavelength of 0·94 μm are presented. These films show bolometric responses at temperatures in the resistive transition regions which are strongly dependent on the bias current. For 0·94 μm radiation, electronically chopped at 20 Hz, measurement of a meander bridge yields a bolometric responsivity of approximately 6·1 V/W.

Superconducting photon detectors have the following advantages over their semiconducting counterparts:

(1) less power is required

(2) response is faster (especially quantum effect response)

(3) bandwidth is greater, extending to long wave IR.[1]

These advantages inherent in the operation of superconducting optical detectors have recently led to the development of a number of sensitive optical and infra-red detectors using superconducting thin films.[2–4] The electrical response of superconducting films to optical radiation can be classified into either nonequilibrium response (breaking of Cooper pairs by photons) or bolometric effect (heating of the sample by radiation). For high-T_c $YBa_2Cu_3O_{7-x}$ (YBCO) superconducting films, a nonequilibrium response has been seen in granular films,[5] whereas a bolometric response has been observed in epitaxial films.[6] This Letter reports further strong evidence of static and dynamic bolometric response to infra-red radiation of YBCO epitaxial thin films with relatively high critical current density.

The fabrication process and conditions for our epitaxial films have been described previously,[7] and only a brief summary will be given here. YBCO films were deposited onto single crystal $SrTiO_3$ (100) substrates by DC sputtering using a fixed composition ceramic target in a mixture gas of O_2 and Ar with a mole ratio of 1–5. After sputtering, the *in situ* 500°C postannealing process was applied to make the film superconductive. The thickness of the films was about 2000 Å. The film possesses a critical current density of 10^6 A/cm^2 at 77 K. The films were then patterned by a photolithography and chemical etching process into a 'meander' type microbridge. A typical pattern after the process is shown in Fig. 1; the total length is 19 mm and the width is 30 μm. Low resistance electrical contacts to the films were formed by evaporating Au. A GaAs diode with a radiation power of $6{\cdot}506 \times 10^{-4}$ W emits infra-red radiation at a wavelength of 0·94 μm to the superconducting bridge. The source is modulated by means of an electronic chopper circuit having a 50% duty cycle. A dynamic voltage change ΔV is produced and sent to a low noise differential amplifier with background noise level of 30 μV at 1 kHz. A bandpass filter is used to obtain the expected signals at the correct frequency from the output terminals of the amplifier and a Tektronix 7854 oscilloscope with a bandwidth of 1–40 kHz, a voltage gain of 1, and input impedance of 10 MΩ, is used to analyse the signals.

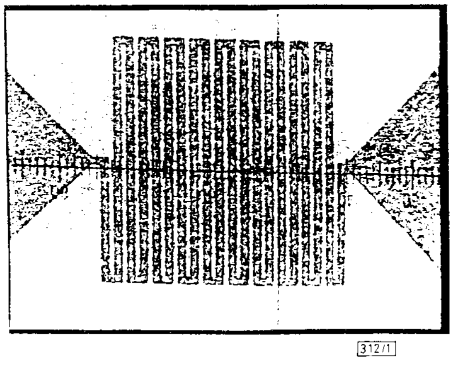

Fig. 1 *Meander type microbridge fabricated by photolithography and chemical etching*

Basically, when the infra-red radiation is incident on the superconducting microbridge, it will lead to a temperature rise. Thus, we use a fixed current passing through the bridge and then measure its R–T curve with and without infra-red radiation. Fig. 2 shows the result of the measurement. The deviation between the two curves is evidence of a temperature rise under illumination. We fix the temperature of the Dewar at 89°K, and apply DC bias to the bridge. Under infra-red radiation, the original resistance of the bridge (point P) changes to a new value (point Q). Thus we obtain a voltage difference between the two terminals where DC is applied. The magnitude of the voltage is proportional to the DC bias level and the partial derivative of resistance with respect to temperature β where $\beta = dR/dT$.

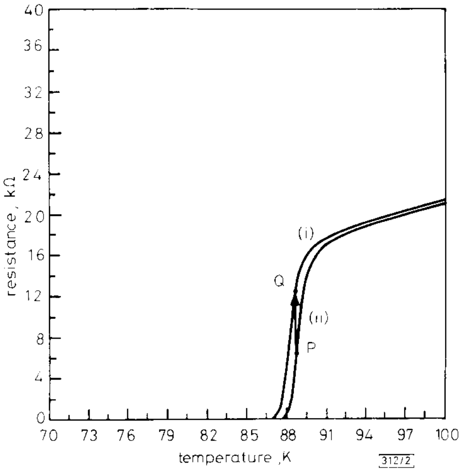

Fig. 2 *Resistance against temperature curves under infra-red radiation and without infra-red radiation*

Shift between the two curves is due to infra-red absorption effect
(i) with infra-red radiation
(ii) without infra-red radiation

Fig. 3 shows the comparison of the measured temperature dependence of the optical response and β as a function of temperature. To obtain a larger response, we need to make

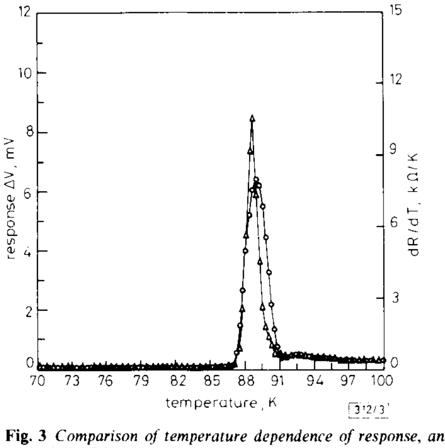

Fig. 3 *Comparison of temperature dependence of response, and dR/dT curve derived from Fig. 2*

△ response
○ *dR/dT*

the bias current I_b as large as possible; however, a larger I_b will suffer from resistance heating. It has been reported that I_b must be limited; thermal runaway will occur if $I_b > (G_s/\beta)^{0.5}$, where G_s is the thermal conductance of the substrate.[1] To avoid this thermal runaway, the 1 μA bias current was chosen in the response measurement. It can be seen that the measured temperature dependence is in good agreement with the 1 μA dR/dT curve shown, which is derived from the R-T curve in Fig. 2. This result is consistent with a transition edge bolometric mechanism reported by other authors. The shift between the two peaks shown in Fig. 3 is simply due to thermal heating of the superconducting bridge by the radiation. Fig. 4 shows the dynamic signal response at 100 μA bias measured at 20 Hz and 2 kHz modulation frequency. In accordance with the equation of the responsivity $\mathscr{R}$ of a bolometer, $\mathscr{R} = I_b \beta \eta / G(1 + i\omega\tau)^{0.5}$, where η is absorption rate, and τ the thermal time constant, we can estimate the responsivity $\mathscr{R}$ as 6·1 V/W (20 Hz). If we consider the Johnson noise only, the noise equivalent power (NEP)[8] can be calculated as $(kTR/\mathscr{R}^2)^{0.5}$ and is equal to $1.02 \times 10^{-9}\,\mathrm{W\,Hz^{-0.5}}$. Thus, the detectivity of the detector D defined as $(area/NEP)^{0.5}$ has a value of $2.363 \times 10^3\,\mathrm{cm\,Hz^{0.5}\,W^{-1}}$.

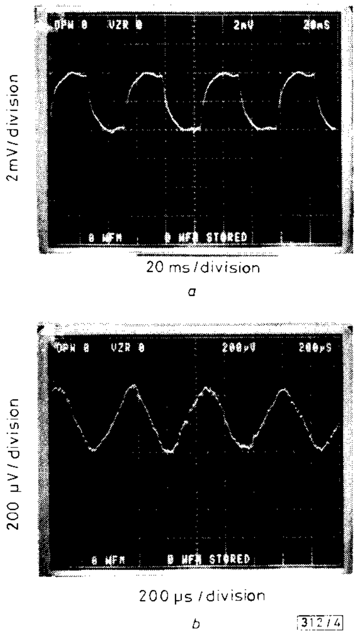

Fig. 4 *Meander type bolometer response to modulated radiation*
a 20 Hz modulation
b 2 kHz modulation

Even though larger I_b will lead to a larger response signal, too large an I_b will also cause the effect of thermal runaway as mentioned in the preceding paragraph. The bias current dependence of the response signal at 88·5 K, 2 Hz is shown in Fig. 5. It is observed that the signal does not increase when the bias current exceeds 100 μA; at a higher level of bias current, a decrease in signal magnitude results. This indicates that there is a constraint in designing the bolometric detector.

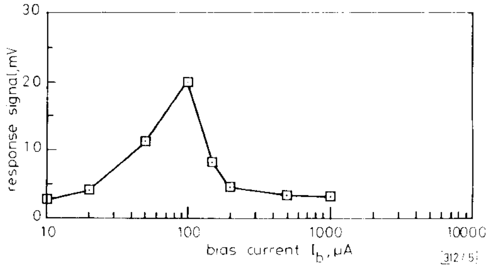

Fig. 5 *Magnitude of response signal against bias current*

The sample used for measurement is grown on $SrTiO_3$ with $\beta = 6\,\mathrm{k\Omega/K}$. Hwang *et al.*[8] have determined that at low frequency the total thermal conductance of the bolometer can be estimated as $G_s = g_s \,.\, A \,.\, a^{-1}$, where A is the area of the bolometer, a is defined as $(A/2\,.\,\pi)^{0.5}$, and g_s is the thermal conductivity of the substrate. For $SrTiO_3$, g_s is equal to $0.18\,\mathrm{W\,cm^{-1}\,K^{-1}}$ and the area of the bolometer is $5.7 \times 10^{-3}\,\mathrm{cm^2}$. Thus, based on the equation for limited I_b, $(G_s/\beta)^{0.5}$, the upper limit of I_b is 2·3 mA.

In summary, based on experimental results, we have shown that $YBa_2Cu_3O_{7-x}$ epitaxial films function as superconducting bolometers. The responsivity of the detector is 6·1 V/W (20 Hz) and the detectivity is estimated to be $2.363 \times 10^3\,\mathrm{cm\,Hz^{0.5}\,W^{-1}}$ considering Johnson noise only.

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PHASE NOISE IN COHERENT SYSTEMS: BASIC MODEL FOR SIMULATIONS

Indexing terms: Noise, Modelling, Optical receivers

For modelling filtered phase noise more efficiently, the number of numerical samples can be reduced by the method of Foschini *et al.*, making use of the Radon-Nikodym theorem. In contrast to this abstract formalism, the Letter reviews the underlying principles using only very basic techniques of probability theory. As a consequence, a transparent, more intuitive understanding is developed, which allows a simple error estimation. The deduced formulas depend only on the modelling of phase noise as Brownian motion, but not on the details of the filtering process.

Introduction: Modelling of coherent optical receivers is presently of great interest. In such a system, the optical and local laser oscillator signals are superimposed on a photodiode. A bandpass filter selects the intermediate frequency (IF) of the photocurrent. The filter converts the time dependent laser